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(54) Title: A METHOD AND SYSTEM FOR PROCESSING AND ANALYZING DIGITAL TERRAIN DATA

(57) Abstract: A method for processing and analyzing digital terrain data utilizing Digital Terrain Elevation Data (DTED). The method comprises defining approach azimuth and visibility limitations angle which are used for defining directional fans by determining fan opening angle, fan azimuth, and maximal range for terrain analysis. At least one directional fan data set is constructed from at least one source point within the DTED, where the directional fan includes line of sight information between said source point and DTED points located within said directional fan. The method further comprises interrogating said data sets by one or more queries to obtain terrain information for given approach conditions.

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**A METHOD AND SYSTEM FOR PROCESSING AND ANALYZING  
DIGITAL TERRAIN DATA**

**Field of the Invention**

The present invention relates to the fields of data processing, mission planning, mission execution, and Digital Terrain Modeling (DTMO). More particularly, the invention relates to a method and apparatus for processing and analyzing Digital Terrain Elevation Data (DTED) for mission planning and on-line re-planning.

**Background of the Invention**

Digital Terrain Elevation Data (DTED) generally consists of a two-dimensional array of terrain elevation points, each of which specifies the height of a terrain point above sea level. Therefore, it constitutes a convenience terrain map for computer representation and analysis. Unlike regular topographic maps, which represent terrains by continuous contour lines of equal heights, a DTED is composed of equally distant terrain elevation points, and is analyzed and processed for construction of Digital Terrain Models (DTM) according to the specific requirements of the particular intended use.

For instance, in US 5,086,396 a DTED in which intervals between adjacent points are of 300ft is utilized to generate DTMs intended to help in flight navigation and mission management. The DTED is utilized to generate DTMs in which surfaces featuring potential danger (e.g., collision) to the air vehicle

at its altitude, are displayed in different colors, according to the degree of threat they possess. Such DTMs can be easily generated by thresholding the DTED with respect to air vehicle altitude. However, this operation requires processing of each and every point in the DTED of interest, which can result in a costly computation time.

The computation complexity and processing time required to analyze a DTED become even more problematic when there is a need to examine the relations between the DTED points for extracting sophisticated DTMs. In US 5,504,686 several DTMs are constructed from a DTED in which the intervals between adjacent points are typically of 800 meters. In said patent "hideability" and "flyability" DTMs are generated for mission planning. The "hideability" DTM is obtained by applying a "hideability transformation" to each and every point in the DTED. The "hideability transformation" is obtained by computing a line of sight area calculation between each point in the DTED to each and every point within an area of some radius R (on the order of thirty miles, i.e., computing a line of sight area to more than 11220 points within said radius). Similarly, the "flyability" DTM is generated by calculating a "slopesness" value to each and every point in the DTED, which is based on the heights of the eight points located in its proximity.

Because of such approach, a vast database is produced, most of which is eventually left unused and is therefore unnecessary. Other results of this

approach are a large amount of memory and processing time required to carry out a specific query in such data bases.

As will be appreciated by those skilled in the art, the generation of such sophisticated DTMs involves many complex computations, and thus results in substantially long computation time which is unacceptable in real time applications. There is therefore a great need for improved DTED processing and analyzing methods, which allow faster processing and involve fewer computations in the DTM generation process.

It is an object of the present invention to provide a method and system for the fast and efficient generation of Digital Terrain Models (DTMO) utilizing a simplified and compact representation of DTED point.

It is another object of the present invention to provide a method and a system for DTMO generation, which requires a minimal set of data per point of area of interest, and which can be efficiently stored in a compressed form.

It is a further object of the present invention to provide a method and a system for mission planning by terrain analysis and study, via on line update and inquiry of DTMOs.

It is still another object of the present invention to provide a method and a system for increasing compression rate of the data required for the construction of Mission Digital Terrain Models (MDTMO) for large terrain areas.

It is still a further object of the present invention to provide a method and a system for minimizing the inquiry time that is required to obtain the information required to construct MDTMOs, and to retrieve pertinent data from MDTMOs.

It is yet another object of the present invention to provide a method and a system for the on line inquiry of mission state such as exposability of area and maps of dominance/weakness areas.

It is a further object of the present invention to provide a method and a system for the on line analysis of mission state in combination of communication ability, exposability, and mission conditions such as weather and vehicle performance envelope.

Other objects and advantages of the invention will become apparent as the description proceeds.

### Summary of the Invention

The present invention provides a method and a system for processing and analyzing terrain data for mission planning and re-planning. The term "mission vehicle" (e.g., air vehicle) is used herein to refer to transportation means capable of delivering the means required to carry out the mission (e.g., mission force), according to the mission assignment. The terms "vehicle performance" is meant to refer to the characteristics of the transportation means, such as velocity, physical limitations such as shell, and the like.

The term altitude is used herein to refer to the height measured relative to sea level, and the terms "exposable height" and "line of site" are used herein to refer to DTED points for which an eye contact can be established from one point to another point, and is also meant to refer to the visibility which may be achieved utilizing vision equipment, such as digital/analog cameras and other types of sensing equipment. The term "exposability conditions" refers to terrain characteristics which enable the determination of the azimuth, distance and/or altitude of approach in which a mission vehicle/force is exposed to the mission destination, and vice versa, i.e., the terrain characteristics which enable the determination of the azimuth, distance and/or altitude of approach in which the mission destination is exposed to the mission vehicle/force. The term "limitations angle" refers to the visibility restrictions which are present due to mission vehicle and/or optical equipment payload (e.g., gimbals angles).

The term mission vehicle/force state refers to the exact location, and orientation in three dimensional space, of the mission vehicle/force. The mission vehicle/force state is usually uncertain during the stages of mission planning, and is usually resolved during progressive stages, after an optimal track is determined. The term target is used here to refer to terrain ground points which are in the mission area of interest (e.g., mission destination).

The present invention is directed to a method and system for processing and analyzing digital terrain data. The terrain data is obtained in the form of a Digital Terrain Elevation Data (DTED). The general azimuth of approach of the mission vehicle/force and visibility limitations angle are used for defining directional fans, where the general azimuth of approach is preferably the azimuth from a starting point to the destination of the mission vehicle/force. The directional fans define an angular area and include data sets including the line of sight information between a source point and other DTED points within the angular area of the fan. The angular area of the directional fan is the angular area having a vertex at the fan source point and area defined by fan opening angle, fan azimuth and maximal range for terrain analysis, where the fan azimuth is preferably defined by the azimuth of the bisector of said opening angle and the maximal range for terrain analysis defines the maximal distance between the fan source point and other points within the fan's angular area.

At least one directional fan is constructed from at least one source point within the DTED, which contains the line of sight information between the source point and DTED points located within the directional fan. Optionally, the data of the directional fans may be compressed by applying a data transformation to obtain a compact data arrangement. The directional fan data may be then used to aid mission planning by means of queries for interrogating the compressed data sets to obtain terrain information for given approach conditions.

Optionally, the fan azimuth is determined according to the approach azimuth. The fan opening angle may be determined according to the visibility limitations angle. An angular resolution for each directional fan may be defined as the smallest fraction of the opening angle to be used to derive exposable heights data set(s), and may be determined according to the fan opening angle and fan maximal range.

According to one possible embodiment of the invention the fan azimuth is in the opposite azimuth ( $180^\circ$  angle shift) to the approach azimuth. The directional fan(s) preferably includes one or more data set(s) of exposable heights, by evenly dividing the fan area into angular sections according to the fan angular resolution; constructing a data set of exposable heights for each angular section by computing for each point within the angular section the distance and elevation angle of the point relative to the fan source point; determining for each of these points if the point is in line of sight with the fan



source point; and discarding the information related to the points which are not in line of sight with the fan source point, thereby obtaining in each directional fan a data set of exposable heights including the information of the DTED points, within the angular sections, that are in line of sight with the fan source point, and which are in correspondence with the azimuth of the angular section.

According to another preferred embodiment of the invention the data of a directional fan is compressed by the following steps:

- a) defining a tolerable deviation for compression which defines the maximal altitude deviation of the compressed data from the original un-compressed data;
- b) for each data set of exposable heights defining a line of exposable heights which is drawn between the points, of the respective angular section, that are in line of sight with the fan source point, starting with the nearest point and ending with the farthest point, in their respective sequence relative to the source point;
- c) for each line of exposable heights defining a sleeve of tolerable deviation defined by the line of exposable heights and a line parallel to and above said line of exposable heights, where the distance between said lines equals the size of the tolerable deviation  $D$ ;
- d) for each angular section compressing the data of the line of exposable heights by performing the following steps:

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- d.1) drawing the longest straight line possible within the sleeve of tolerable deviation starting at the edge of the sleeve;
- d.2) defining an end point on the longest line within the sleeve at the farthest section where the longest line intersects with one of the boundaries of the sleeve;
- d.3) drawing the next longest line starting from the end point of the previous line; and
- d.4) repeating steps d.1) to d.3) until the end the sleeve is reached.

Optionally, the data compression of the line of exposable heights is performed starting from the farthest points within the angular section and proceeding toward the source point. The data of each directional fan may be represented utilizing a polar coordinate system, and the data obtained from a directional fan may be transformed from a polar representation into a Cartesian representation.

The pertinent data can be obtained from the directional fan(s) via a lookup process according to the angular displacement of the respective angular section, and the data obtained by query interrogation may further comprise interpolation of the data within an angular section, for obtaining altitude of any desired point by interpolating the points obtained from the compressed line of exposable heights.

According to another preferred embodiment of the invention the fan opening angle is set to  $360^\circ$ , and the interrogation of fan data set is carried out by extracting from each fan data set the lines of exposable heights which are of azimuths which falls within an opening angle directed in the opposite direction (azimuth) of that of the approach azimuth.

The interrogation of the fan data set is preferably carried out by extracting from each fan data set the lines of exposable heights which are of azimuths which falls within an opening angle directed in the opposite direction of that of the approach azimuth.

In a preferred embodiment of the invention the interrogation of the fan data set is carried out by one or more queries for detecting the minimal altitudes in which communication and/or line of sight can be established with DTED points. In particular, the queries may be utilized to determine the minimal altitude required to establish line of sight for a given distance and approach azimuth, the minimal altitude required to establish communication with a given point, and the minimal distance required to establish line of sight with terrain points for a given altitude and azimuth of approach.

The interrogation of the fan data set is carried out by one or more queries with different levels of uncertainty:

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- Queries of unknown azimuth of approach, utilizing a general azimuth of approach or a range of possible approach azimuths, and using the worst case results;
- Queries with a known azimuth of approach or a general approach path (track), but in which the exact state is partially known or unknown; and
- Queries for a specific location for quickly analyzing an exact location.

### **Brief Description of the Drawings**

In the drawings:

- Figs. 1A and 1B schematically illustrates a preferred process for analyzing and processing DTED;
- Fig. 2A illustrates the construction of exposability fans;
- Figs. 2B and 2C illustrates a preferred method for constructing vectors of exposable heights;
- Fig. 3 illustrates a method of data sets compression according to one embodiment of the invention;
- Fig. 4 demonstrates a directional fan construction;
- Fig. 5 exemplifies the steps of interrogating a directional fan DB by a query;
- Figs. 6A-6C exemplifies the defined/undefined azimuth of movement, and track dependent queries; and
- Figs. 7 show the structure of a communication fan.

### **Detailed Description of Preferred Embodiments**

The present invention is directed to the generation of Mission Digital Terrain Models (MDTMO) required for mission planning, based on the generation of a particular, simplified, and compressed mission model which is created according to mission parameters and terrain information. According to a preferred embodiment of the invention the Digital Terrain Elevation Data (DTED) is utilized to extract an exposability model and a communication model, based on pre-processed directional fans of exposable vectors, which are then combined and processed into a MDTMO, which may be then efficiently used to effectively analyze terrain data with respect to mission specific parameters, in real time.

As will be explained in details hereinafter, the exposability DTMO is extracted from pre-processed directional fans of vectors of exposable heights, which are analyzed according to mission specific parameters (e.g., azimuth of approach), to reveal exposability DTMO points which satisfy the ground detection of the mission force/vehicle. The communication DTMO is also extracted from pre-processed directional fans of exposable vectors according to mission specific parameters, but for indicating DTMO height points which are capable for communication between given point(s) and the mission force/vehicle. The final MDTMO is generated utilizing the exposability and communication DTMOs, in combination with additional data concerning the mission force/vehicle

performance envelope as well as other miscellaneous information which may be deemed relevant to the specific conditions (e.g., the weather).

Fig. 1A is a flow chart exemplifying a process for generating DTMOs and MDTMOs according to the method of the invention. In the first step 100 of the pre-processing stage, directional fans of vectors of exposable heights (404 in Fig. 4) are extracted from the DTED. The main purpose of this step is to determine and collect terrain information that corresponds only to those sets of points which are of interest according to some predefined conditions. In this way, only the DTED information pertaining to the mission is gathered, and all the other DTED information, which is irrelevant to the specific mission plan (e.g., azimuth of approach), is discarded. This step results in a compact and reduced data set, which is convenient for data processing according to the method of the invention. In step 101, the reduced data set that was obtained is compressed by eliminating redundant data points and by changing the data representation of the remaining data points into a compact and minimal representation, by applying a data transformation.

The compressed data sets that are obtained in step 101 are then interrogated (by queries), in step 103, according to different aspects of the mission plan. The queries performed in step 103 are utilized to generate various types of DTMOs. Some of the DTMOs which are of particular importance in the present invention are the communication DTMO (step 106), the exposability DTMO

(step 105), and safety conditions (step 107). Together with the mission force/vehicle data (e.g., velocities, heights, performance capabilities, etc.) (step 104), all the above mentioned DTMOs are processed in step 108 to obtain the MDTMO in step 109, which can provide all the pertinent information required for mission execution.

### Pre-processing:

With reference to Fig. 4, in which a directional fan is illustrated, the various DTMOs are generated utilizing two fundamental data sets, one data set comprising vectors of exposable heights (404) which are exposable by the terrain points (hereinafter source points), and the other data set comprising directional fans (220 in Fig. 5), consisting of the abovementioned vectors of exposable heights (404). The directional fans 220 are the initial data set, constructed from DTED points, which are utilized for the processing of DTED points according to the method of the invention. Each directional fan 220 is a collection of DTED information pertaining to a particular source point 200 (fan vertex). More particularly, each directional fan holds the terrain information, pertaining to the source point 200, and which is within a predefined radius  $R_{\max}$  and a fan opening angle  $\phi$  (403). The directional fans are constructed from DTED to include terrain information in correspondence with approach azimuth 223, as shown in Fig. 2A.

As will be explained in details and illustrated hereinafter, each directional fan 220 collects the terrain line of sight information that is relevant to the mission specific conditions within a given terrain zone. This treatment substantially reduces the amount of data and processing required for producing various terrain models according to the method of the invention.

Vectors of heights exposable by the Targets:

These vectors (also termed herein as vectors of exposable heights 404) constitute a fundamental unit of information, which includes heights and distances indicating the minimal altitude required to be in a line of sight (i.e., eye contact) with an examined source point 200 in the DTED. The vectors 404 (Fig. 4) are computed from a two-dimensional terrain profile 210, taken from the directional fans of DTED points 220, as shown in Figs. 2A, 2B, and 2C. Each point in a vector 404 is represented by its horizontal distance  $L$  from the source point 200 and its elevation angle  $\delta$  (Fig. 2C). The vector of exposable heights 404 are constructed from the line of sight points 203, which are the DTED points within said profile which has direct line of sight 215 to the source point 200.

By the construction of vectors of exposable heights data sets 404, the selected terrain can be examined to reveal the minimal height required to maintain communication with a given ground point (e.g., control station), and the minimal height in which a given source point (e.g., Targets) may be exposed.



During this step (step 100 in Fig. 1) the elevation angle  $\delta$  between each point in the terrain profile 210 and the source point 200 is computed (hereinafter angle of sight), and only points having an angle of sight that is greater than the angle of sight of the previous point are preserved. The outcome of this process is that Hidden points 202 are discarded, since the peak points 203 hide them, and they do not possess a direct line of sight with the source point 200. Thus, a line 207 of exposable heights is obtained, which contains only those terrain points, within the two-dimensional terrain profile 210, which are exposable by the source point 200.

In this way redundant information (related to hidden points 202) is discarded, and thus each directional fan 220 maintains only the information which is relevant according to the mission specifics (azimuth 223,  $R_{\max}$ ,  $\phi$ , etc.). While this is a preferred method to discard redundant information according to the invention, it should be noted that the information included by the directional fans 220 may be compressed utilizing other methods suitable for the data processing that will be discussed hereinafter.

It should be noted that according to a preferred embodiment of the invention the operations performed during the data processing steps also involve careful examination of additional aspects which are not discussed here for the sake of brevity. For instance, for the calculation of line of sight between terrain points

the earth roundness (curvature) should also be considered, and for the communication DTMOs, the communication line curvature, as well as other pertinent aspects (e.g., the weather), which should also be considered.

Data compression:

This step (101 in Fig. 1A) is carried out in order to reduce the size of the data set of exposable heights in each line of exposable heights 207. The compression step 101 determines a minimal number of points in a line of exposable heights 207, which is required to obtain a line which deviates from the prior uncompressed line of exposable heights 207 within the tolerable deviation (209) allowed for the purpose of compression (e.g. less than 50 meters above/below the line of exposable heights 207). For example, DTED points 201 (Fig. 2B) are discarded since they fall within the tolerable deviation 209. This reduction in the number of data set points also substantially reduces the time durations required for each query to examine various aspects of the selected terrain, due to the reduction in the amount of information in each directional fan 220. The compression step is performed on the lines of exposable heights 207 of each and every directional fan 220, to yield a compressed set of directional fans.

The compression starts by defining the maximal deviation ( $D$ , shown in Fig. 3) allowed from each point in the line of exposable heights 207. The allowed deviation  $D$  (set of points 300 in Fig. 3) is allowed to be introduced only above

the line of exposable heights 207, i.e. for each point  $(207) + D = (300)$ . Thereby, a "sleeve" of tolerable deviation is defined between the two lines, 207 and 300. The compressed data set is obtained from the set of the longest straight lines 310a-c that can be drawn within the sleeve of tolerable deviation. One way to carry out the compression process may be by performing the following steps:

- 1 – Generate a sleeve of tolerable deviation by adding the tolerable deviation  $D$  to the altitude of each point in the original un-compressed line of exposable heights;
- 2 – Draw the longest straight line possible (310a) within the sleeve of tolerable deviation starting at the edge of said sleeve;
- 3 – define an end point (311) on said longest line, within said sleeve, at the farthest section where said longest line intersects with one of the lines (207 or 300) of said sleeve, where said end point is preferably located between the nearest pair of points located on the line of exposable heights (207) and on the upper line (300) of said sleeve, before said intersection;
- 4 – draw the next longest line (310b) starting from the end point (311) of the previous line; and
- 5 – repeat steps 2 to 4 until the end said sleeve is reached.

The data processing carried out according to the method of the invention is also unique due to the approach utilized to solve the exposable problem. In the case of an air vehicle, for instance, an altitude should be determined, at which each target can be exposed. The visibility of air vehicles is confined to the

limitations angle, and therefore the targets can be exposed only within this range of angles  $\emptyset$ . On the other hand, each of the targets can expose the air vehicle within the same range of angles, but with a  $180^\circ$  angle shift (since the exposability problem is symmetric). Therefore, the exposability problem can be inverted and solved according to the observability of terrain points (in the view of the targets), and the air vehicle altitude in which the targets are visible to the mission force can be resolved in this way.

The terrain is analyzed from a terrestrial point of view (i.e., targets' sight), but within the air vehicle limitations angle. The directional fans 220 consist of a set of vectors of exposable heights 404. The vertex of each directional fan is the source point 200, and the fan azimuth 401 is preferably the azimuth of the bisector of the fan opening angle, which is preferably opposite in direction to the approach azimuth 223 of the mission force (i.e.,  $180^\circ$  angle shift), opening angle  $\phi$  (403), maximal range  $R_{\max}$ , and angular resolution 402 of  $\theta$  degrees between each vector of exposable heights 404. The maximal range  $R_{\max}$  is determined according to the destination terrain, the targets, and mission vehicle/force characteristics (e.g. visibility conditions). The opening angle used to construct the directional fans is determined according to the vehicle limitations angle.

As was previously mentioned, the directional fans 220 includes fundamental data sets according to the method of the invention. In a preferred embodiment

each directional fan 220 comprises: the maximal range  $R_{\max}$ ; directional fan opening angle  $\phi$  (403); fan azimuth 401; maximal compression deviation  $D$ ; height of source point 200 (measured relative to sea level); spatial location of the source point 200 in two-dimensional coordinates plain; vectors of exposable heights 404; and the direction of each vector of exposable heights.

#### DTMOs:

The digital terrain model obtained after performing the pre-processing steps (100 and 101) results in a Data Base (DB) of directional fans 220 consisting of a compressed vector of heights 404, which includes all the pertinent information required for the planning of the specific mission. The data processing for the mission planning proceeds by introducing queries concerning different mission aspects as shown in step 103 of Fig. 1A. This is an intermediate step in which a unique DTMO is constructed for each mission aspect. For example, in one preferred embodiment of the invention, the exposability DTMO, communication DTMO (which usually includes a single directional fan), are constructed and then used in a later processing stage 108 in which the MDTMO is constructed.

Each DTMO contains information relevant to a specific mission aspect. Therefore, each query performed requires a lookup process limited only to fetching the desired information, which does not involve any complex computation. In general, each DTMO includes numerous directional fans 220

covering the mission area, where each directional fan is directed in the opposite direction of the mission force/vehicle approach direction, and has an opening angle set according to the vehicle limitations angle.

An exemplary query process is sketched in Fig. 5. The relevant terrain model of compressed directional fans 500 is interrogated by a query. Each directional fan 220 is looked up and the relevant data 520 is retrieved, obtaining the respective DTMO shown in 501. The query result can be processed and displayed in the form of continuous contour lines in 502, each of which represents points having the same properties e.g., points which determine minimal altitude required for satisfying certain exposability conditions or which determine mission area coverage.

#### Queries:

A query will typically interrogate the DTMO DB of compressed directional fans for data concerning the altitude and/or distance required to satisfy predetermined conditions. The queries are performed in various stages of uncertainty. More particularly, these stages may be categorized into the following levels of uncertainty:

- 1 - Unknown azimuth of approach: in this case the queries are established utilizing a general azimuth of approach or a range of possible approach azimuths, and the worst case results is therefore used;

- 2 - Known azimuth of approach: in which a general approach path (track) is known, and therefore these queries provides more accurate results;
- 3 - Given specific location: this type of interrogation is typical for "real-time" scenarios, wherein there may be a need to quickly analyze the area in which the mission force/vehicle is located during the mission execution.

It should be noted, that regardless of the level of uncertainty, the limitations angle is used to define the directional fan opening angle to be used for these queries.

Few examples of possible queries are explained here below:

1. exposability DTMO for a given distance – this is a DTMO indicating the minimal altitude required to establish line of sight with the target(s) for a given distance and azimuth of approach of the mission vehicle;
2. communication DTMO – this DTMO indicates the minimal altitude required to establish communication with a given point, in any possible location in the selected terrain;
3. exposability DTMO for a given altitude – this is a DTMO indicating the minimal distance that is required to establish line of sight with the target(s) for a given altitude and azimuth of approach of the mission vehicle; and
4. mission execution DTMO (MDTMO) – the combination between an exposability DTMO for a given distance and altitude from ground points in the mission zone, and the communication DTMO, and additional information such

as vehicle performance capabilities. Thus this DTMO represents the suitable trajectory required for mission execution in a given distance(s) and azimuth(s)

### Off-line planning queries

This is a preliminary stage in which usually only mission destination is known and thus the azimuth of approach is not well defined, or that it is known in a general and wide sense. This stage is usually performed well before the mission execution. In the first stages of the off-line mission planning (step 111 in Fig. 1B) the exact approach path is usually not known, and therefore the mission force/vehicle state during the mission execution (azimuths, altitudes, etc.) is not known. In this case the terrain analysis is performed utilizing a rough approximation of the Mission force/vehicle state, and/or ranges of possible values of the same, and of course within the limitations angle. This process is illustrated in step 111 in Fig. 1B. The compressed directional fans data sets (terrain information) 120 are interrogated utilizing said queries which yields DTMOs (DTMO1-DTMO4) which utilize the worst case results.

As the off-line mission planning proceeds, the worst case results obtained for a possible range of approach azimuths are used to define a desired optimal track for the mission force/vehicle. This optimal track is determined according to various aspects. For instance, it may be influenced by the total mission distance and time frames, possible threats, and/or mission force/vehicle performance.



This information is then used to further interrogate the compressed data set 120 with more specific queries. For example, the queries may be used to obtain exposability information over said desired track without indicating a specific mission force/vehicle state. Such interrogation can be used by declaring a desired range from the destination over sections of the track in which the mission force/vehicle is exposed to destination sites. Alternatively, the queries may be used defining a desired duration of time in which the mission force/vehicle is exposed to the destination site.

#### On-line planning queries (mission monitoring)

These types of queries are typically performed during the mission execution, and thus involve more accurate information concerning the mission force/vehicle state. More particularly, in many cases this type of queries are performed for a given location and orientation in space of the mission force/vehicle. As exemplified in step 121 of Fig. 1B, the results that are obtained will usually include DTMOs of exact exposable areas, and/or areas in which communication can be established with another point(s) in space. Therefore, the compressed data sets 120 is analyzed by queries utilizing well defined mission force/vehicle state information, according to the actual location and state of the mission force/vehicle. Correspondingly, the DTMOs information obtained in this case is more accurate.

Typically, on-line queries 121 are used for mission re-planning, which may be required for instance during the mission execution in situations in which an alternative mission plan is needed to successfully finalize the mission. Such scenarios are mostly probable due to new information gathered during the mission execution, or due to unexpected developments (e.g., weather conditions). However, such re-planning may also be carried out utilizing the off-line queries, which were previously discussed, according to the level of uncertainty and the re-planning needs.

#### On/off-line planning with different stages of uncertainty

According to one preferred embodiment of the invention, the direction of approach of the mission vehicle can be defined according to one of the following:

- Defined azimuth: to resolve queries having a defined azimuth of approach. In this case two adjacent vectors of exposable heights 404 are interpolated in each directional fan. The two adjacent vectors of exposable heights are the two vectors which have an azimuth in the vicinity of the azimuth that is opposite to the azimuth of approach. For instance, in Fig. 6A, a query is performed for a given azimuth of  $241^\circ$  in which the vectors of exposable heights with azimuths of  $60^\circ$  and  $65^\circ$  are interrogated.
- Undefined azimuth: in such queries all the vectors of exposable heights in a directional fan 220 are utilized. Such a case is depicted in Fig 6B,

where for an undefined azimuth a query is performed, and each and every vector (in azimuths  $50^\circ$ ,  $55^\circ$ , ...,  $80^\circ$ ) of exposable heights in the directional fan is interrogated, and usually the worst case result from all of the vectors of a fan is chosen.

- Track dependant: in this case a well defined track is given to the destination 600. Correspondingly, different suitable azimuths are used to interrogate vectors of exposable heights of different directional fans in the terrain model DTMO DB. Thus vectors of exposable heights 404 having different azimuths are selected in each directional fan. This case is exemplified in Fig. 6C. In this case the query performed in each directional fan is carried out only on the vectors of exposable heights 404 having azimuth that falls between the edges of the limitations angle  $\lambda$ . In this example the vectors of exposable height in directional fan F1 that are interrogated are those having azimuths of  $50^\circ$  and  $55^\circ$ , and in directional fan F2 the vectors of exposable height that are interrogated are those having azimuths of  $75^\circ$  and  $80^\circ$ .

#### Communication DTMO:

The communication model is usually constructed from a single directional fan the base of which is located at the mission control center, and its vectors of exposable heights 404 consist of points which are in line of sight with the control center. 701. This terrain model is treated in a similar fashion to extract DTMOs that indicates the minimal altitude in which communication can be

established with the mission control center. The directional fan azimuth 702 is computed according to the path between the mission control center 701 and the destination 600, as shown in Fig. 7. It should be noted that the destination 600 may be a single point, as well as a collection of points defining a destined area for the mission assignment.

#### Exposability DTMO:

The exposability DTMO includes a set of directional fans, each of which corresponds to a terrain point in the DTED of the mission area. These directional fans include all the information required to respond to exposability queries, for a given approach azimuth in the mission area. The exposability DTMO is created by performing the following steps:

- 1 – defining the approach azimuth; and
- 2 – generating exposability fans for each point according to the approach azimuth, and directional fan definitions (angular resolution  $\theta$ , opening angle  $\phi$ ; etc.).

As will be appreciated by those skilled in the art, the method of the invention may be carried out in different ways. For example, according to one preferred embodiment of the invention instead of constructing directional fans for each point, a DB of 360° fans is constructed, and only the relevant vectors on each fan are used for a given azimuth of approach.

According to another preferred embodiment of the invention the size of the directional fans DB is further reduced by reducing the number of points required for different terrain cells according to the curvature and complexity of the different terrain cells. Thereby, terrain areas which are relatively flat can be modeled by the use of a small set of DTED points, which results in a significant reduction in the size of the DTMO (i.e., less data is required).

The size of the DTMO is even further reduced by utilizing a dynamic determination of the opening angle and angular resolution for each directional fan. In this way, for example, in areas which are relatively flat the angular resolution required may be reduced to further reduce the data of the directional fan.

It should also be noted that the method of the invention provides an efficient DTMO data base that enables query interrogation via a lookup process. Since the information is organized in the form of vectors of exposable height in the directional fans, for each query only the pertinent vectors are extracted from each fan in a lookup process. The data in the DTMO is preferably organized in a polar format (i.e., utilizing polar coordinates), which further simplifies the query lookup process. After the pertinent vectors are extracted from each directional fan, a line of sight is obtained by an interpolation of the vector data, and the results are transformed into a Cartesian coordinate system, as relevant to the assignment.

The above examples and description have of course been provided only for the purpose of illustration, and are not intended to limit the invention in any way. As will be appreciated by the skilled person, the invention can be carried out in a great variety of ways, employing techniques different from those described above, all without exceeding the scope of the invention.

**CLAIMS**

1. A method for processing and analyzing digital terrain data, comprising:
  - a) providing Digital Terrain Elevation Data (DTED);
  - b) defining an approach azimuth and a visibility limitations angle;
  - c) defining directional fans by determining a fan opening angle, a fan azimuth, and a maximal range for terrain analysis;
  - d) constructing at least one directional fan data set, from at least one source point within the DTED, that contains the line of sight information between said source point and DTED points located within said directional fan; and
  - e) interrogating said data sets by one or more queries to obtain terrain information for given approach conditions.
2. A method according to claim 1, wherein the directional fan azimuth is determined according to the approach azimuth.
3. A method according to claim 1, wherein the fan opening angle is determined according to the visibility limitations angle.
4. A method according to claim 3, further comprising defining a fan angular resolution.
5. A method according to claim 4, wherein the fan angular resolution is

determined according to the fan opening angle and the fan maximal range.

6. A method according to claim 1, wherein the fan azimuth is set to the opposite azimuth of the approach azimuth.

7. A method according to claim 4, wherein the directional fan(s) are constructed from one or more data set(s) of exposable heights, by performing the following steps:

- a) evenly dividing the fan area into angular sections according to the fan angular resolution;
- b) constructing a data set of exposable heights for each angular section, by computing for each point within the angular section the distance and elevation angle of said point relative to the fan source point;
- c) determining for each point within a data set of exposable heights if said point is in line of sight with the fan source point; and
- d) discarding the information related to the points within a data set of exposable heights which are not in line of sight with the fan source point,

thereby obtaining in each directional fan data set of exposable heights including the information of the DTED points, within said angular sections, that are in line of sight with the fan source point, and which are of corresponding azimuths.



8. A method according to claim 1 or 7, further comprising compressing the data of the directional fans by applying a data transformation.
9. A method according to claims 7 and 8, wherein the data of a directional fan is compressed by performing the following steps:
  - a) defining a tolerable deviation for compression;
  - b) for each data set of exposable heights defining a line of exposable heights which is drawn between the points, of the respective angular section, which are in line of sight with the fan source point, starting with the nearest point and ending with farthest point, in their respective sequence relative to said source point;
  - c) for each line of exposable heights defining a sleeve of tolerable deviation by adding the tolerable deviation D to the points of said line of exposable heights;
  - d) for each angular section compressing the data of the line of exposable heights by performing the following steps:
    - d.1) drawing the longest straight line possible within the sleeve of tolerable deviation starting at the edge of said sleeve;
    - d.2) defining an end point on said longest line within said sleeve at the farthest section where said longest line intersects with one of the boundaries of said sleeve;
    - d.3) drawing the next longest line starting from said end point of the

previous line; and

d.4) repeating steps d.1) to d.3) until the end said sleeve is reached.

10.A method according to claim 9, wherein data compression of the line of exposable heights is performed starting from the farthest points within the angular section and proceeding toward the source point.

11.A method according to claim 9, wherein data of each directional fan is organized utilizing a polar coordinate system.

12.A method according to claim 11, wherein the data obtained from a directional fan is transformed from a polar representation into a Cartesian representation.

13.A method according to claim 9, wherein the pertinent data is obtained from the directional fan(s) via a lookup process.

14.A method according to claim 9, wherein the data obtained by query interrogation further comprises interpolation of the data within an angular section.

15.A method according to claims 1 to 14, wherein the directional fan data set comprises the maximal range, the fan opening angle, the fan direction, the

maximal compression deviation, the height of the source point, the spatial location of the source point, and the vectors of exposable heights and their direction.

16.A method according to claim 1 or 7, wherein the fan opening angle is set to 360°.

17.A method according to claim 16, wherein the interrogation of the fan data set is carried out by extracting from each fan data set the lines of exposable heights which are of azimuths which falls within an opening angle directed in the opposite direction of that of the approach azimuth.

18.A method according to any one of claims 1 to 17, wherein the interrogation of the fan data set is carried out by one or more queries for detecting the minimal altitudes in which communication and/or line of sight can be established with DTED points.

19.A method according to claim 18, wherein one or more of the following queries are utilized to determine:

- a) the minimal altitude required to establish of sight for a given distance and approach azimuth;
- b) the minimal altitude required to establish communication with a given with a given point; and

- c) the minimal distance required to establish line of sight with terrain points for a given altitude and azimuth of approach.

20. A method according to claim 18, wherein the interrogation of the fan data set is carried out by one or more queries from the following list:

- Queries of unknown azimuth of approach, utilizing a general azimuth of approach or a range of possible approach azimuths, and using the worst case results;
- Queries with a known azimuth of approach or having a general approach path, but in which the exact state is partially known or unknown; and
- Queries for a specific location for quickly analyzing an exact location.

21. A system for processing and analyzing digital terrain data, comprising:

- a) a Digital Terrain Elevation Data (DTED);
- b) means for defining approach azimuth and visibility limitations angle;
- c) means for defining directional fans by determining fan opening angle, fan azimuth, and a maximal range for terrain analysis;
- d) means for constructing at least one directional fan data set, from at least one source point within the DTED, that contains the line of sight information between said source point and DTED points located within the directional fan; and
- e) means for interrogating said data sets by one or more queries to obtain

terrain information for given approach conditions.

22.A system according to claim 21, wherein the fan azimuth is determined according to approach azimuth.

23.A system according to claim 21, wherein the fan opening angle is determined according to the visibility limitations angle.

24.A system according to claim 23, further comprising defining a fan angular resolution.

25.A system according to claim 24, wherein the fan angular resolution is determined according to the fan opening angle and fan maximal range.

26.A system according to claim 21, wherein the fan azimuth is set to the opposite azimuth of the approach azimuth.

27.A system according to claim 24, wherein the directional fan(s) is constructed from one or more data set(s) of exposable heights, by performing the following steps:

- a) evenly dividing the fan area into angular sections according to the fan angular resolution;
- b) constructing a data set of exposable heights for each angular section by

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computing for each point within the angular section the distance and elevation angle of said point relative to the fan source point;

- c) determining for each point within a data set of exposable heights if said point is in line of sight with the fan source point; and
- d) discarding the information related to the points within a data set of exposable heights which are not in line of sight with the fan source point,

thereby obtaining in each directional fan data set of exposable heights including the information of the DTED points, within said angular sections, that are in line of sight with the fan source point, and which are of corresponding azimuths.

28.A system according to claim 21 or 27, further comprising compressing the data of the directional fans by applying a data transformation.

29.A system according to claim 28, wherein the data of a directional fan is compressed by performing the following steps:

- a) defining a tolerable deviation for compression;
- b) for each data set of exposable heights defining a line of exposable heights which is drawn between the points, of the respective angular section, that are in line of sight with the fan source point, starting with the nearest point and ending with farthest point, in their respective sequence relative to said source point;

- c) for each line of exposable heights defining a sleeve of tolerable deviation by adding the tolerable deviation  $D$  to the points of said line of exposable heights;
- d) for each angular section compressing the data of the line of exposable heights by performing the following steps:
  - d.1) draw the longest straight line possible within the sleeve of tolerable deviation starting at the edge of said sleeve;
  - d.2) define an end point on said longest line within said sleeve at the farthest section where said longest line intersects with one of the boundaries of said sleeve;
  - d.3) drawing the next longest line starting from said end point of the previous line; and
  - d.4) repeating steps 2 to 4 until the end said sleeve is reached.

30.A system according to claim 29, wherein data compression of the line of exposable heights is performed starting from the farthest points within the angular section and proceeding toward the source point.

31.A method according to claim 29, wherein data of each directional fan is organized utilizing a polar coordinate system.

32.A system according to claim 31, wherein the data obtained from a directional fan is transformed from a polar representation into a Cartesian

representation.

33. A system according to claim 31, wherein the pertinent data is obtained from the directional fan(s) via a lookup process.

34. A system according to claim 31, wherein the data obtained by query interrogation further comprises interpolation of the data within an angular section.

35. A system according to claims 21 to 34, wherein the directional fan data set comprises the maximal range, the fan opening angle, the fan direction, the maximal compression deviation, the height of the source point, the spatial location of the source point, and the vectors of exposable heights and their direction.

36. A system according to claim 21 or 27, wherein the fan opening angle is set to 360°.

37. A system according to claim 21, wherein the interrogation of the fan data set is carried out by extracting from each fan data set the lines of exposable heights which are of azimuths which falls within an opening angle directed in the opposite direction of that of the approach azimuth.



38. A system according to any one of claims 21 to 37, wherein the interrogation of fan data set is carried out by one or more queries for detecting the minimal altitudes in which communication and/or line of sight can be established with DTED points.

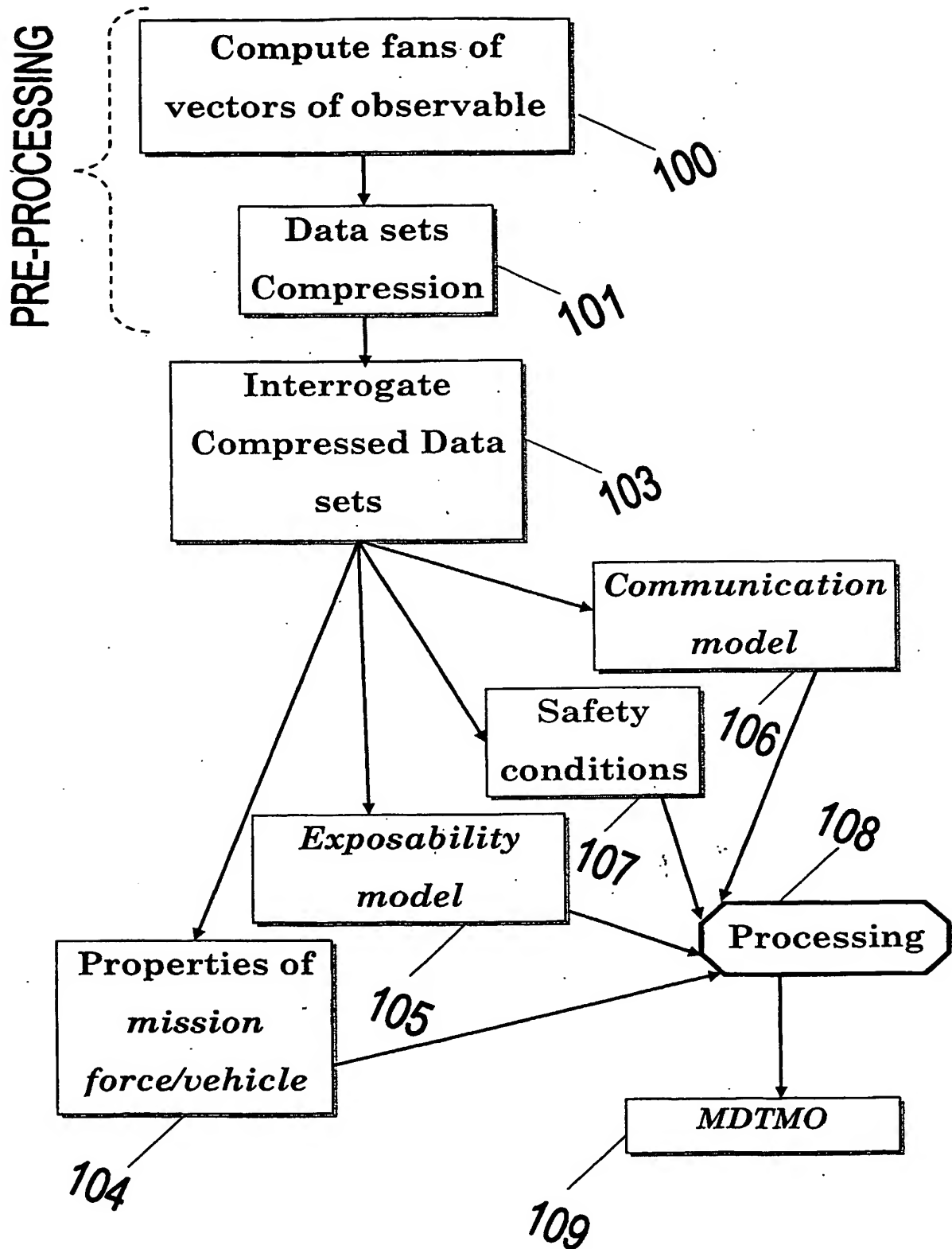
39. A system according to claim 38, wherein one or more of the following queries are utilized to determine:

- a) the minimal altitude required to establish of sight for a given distance and approach azimuth;
- b) the minimal altitude required to establish communication with a given with a given point; and
- c) the minimal distance required to establish line of sight with terrain points for a given altitude and azimuth of approach.

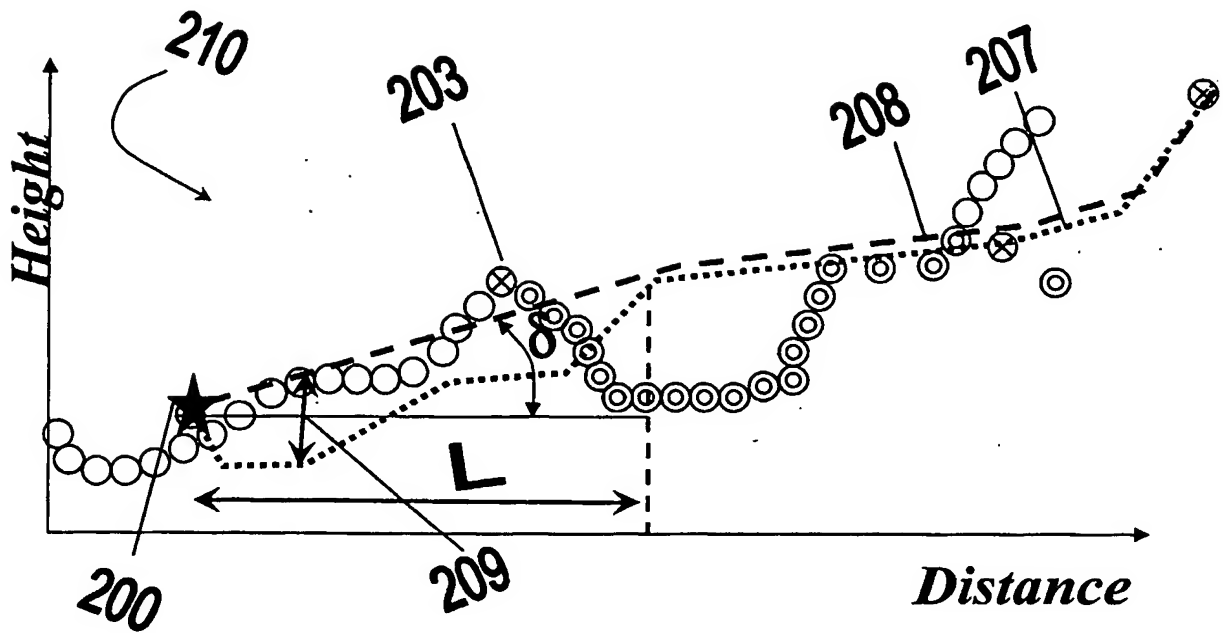
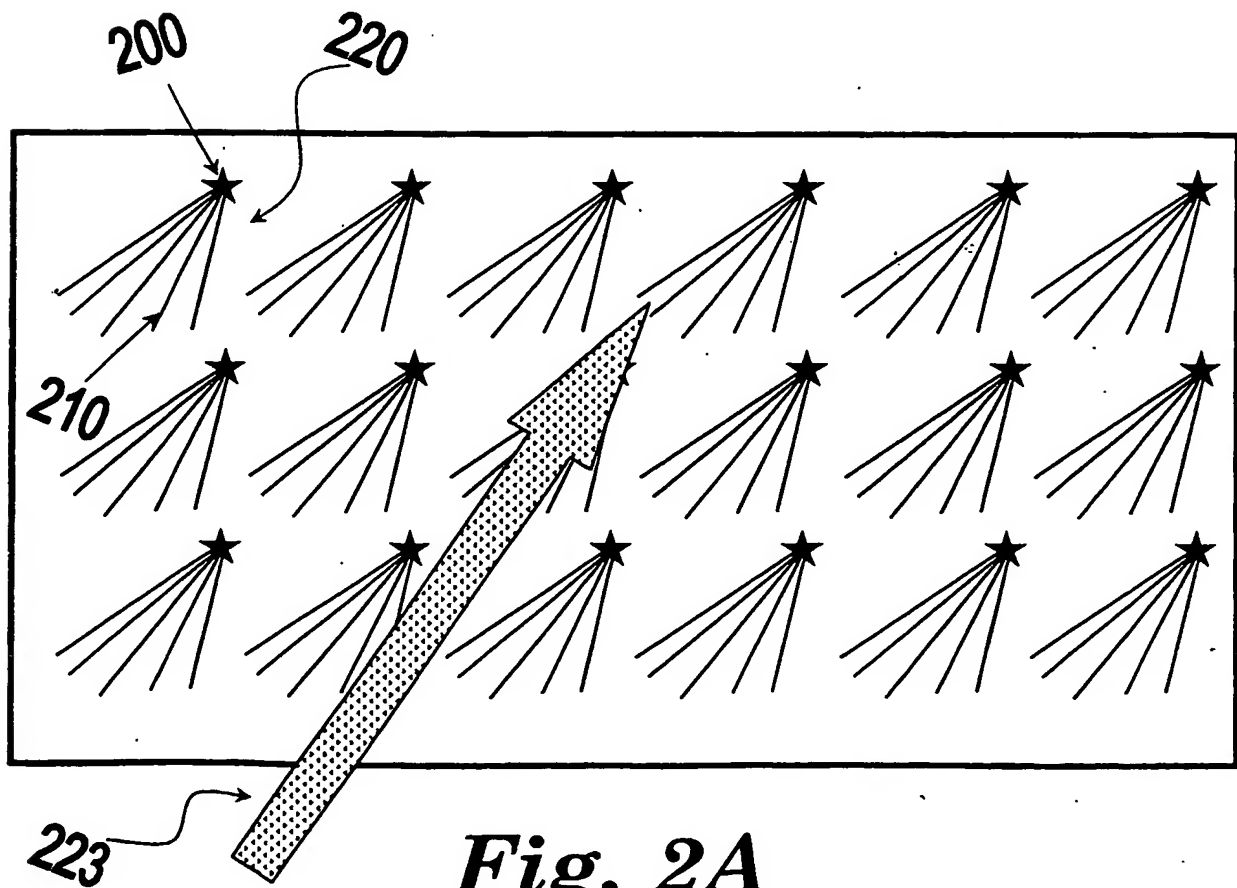
40. A system according to claim 21, wherein the interrogation of the fan data set is carried out by one or more queries from the following list:

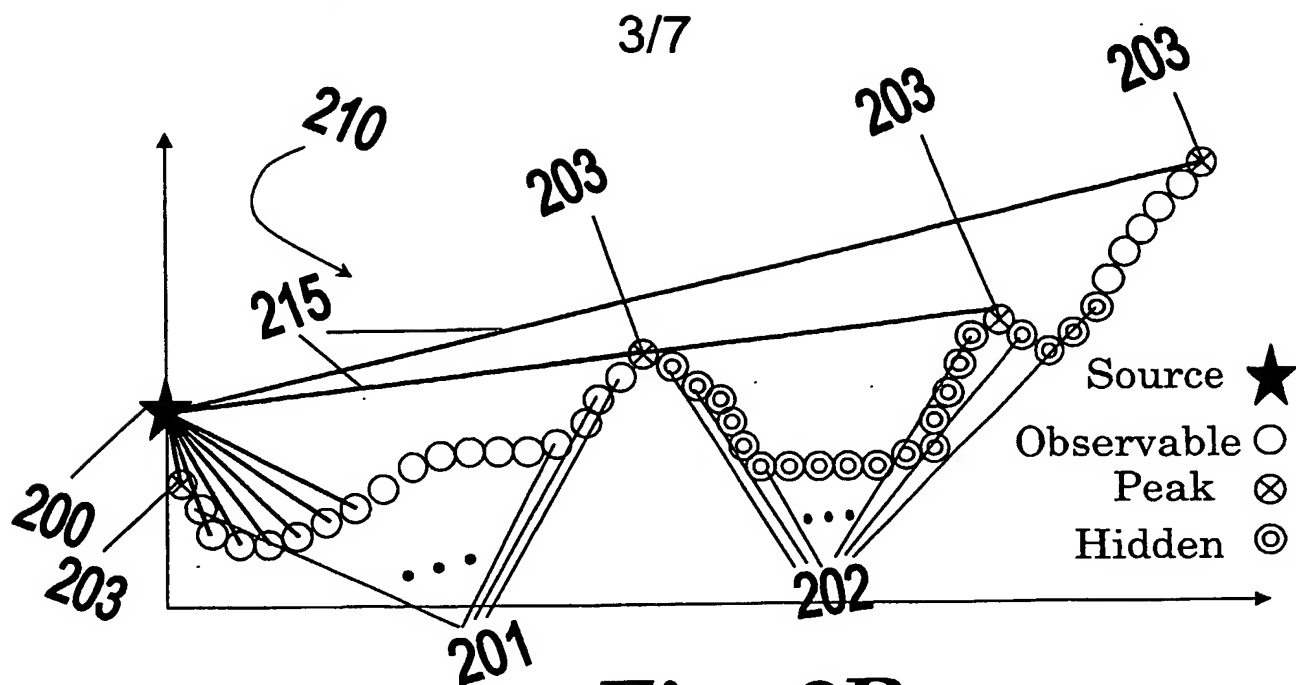
- Queries of unknown azimuth of approach, utilizing a general azimuth of approach or a range of possible approach azimuths, and using the worst case results;
- Queries with a known azimuth of approach or having a general approach path, but in which the exact state is partially known or unknown; and
- Queries for a specific location for quickly analyzing an exact location.

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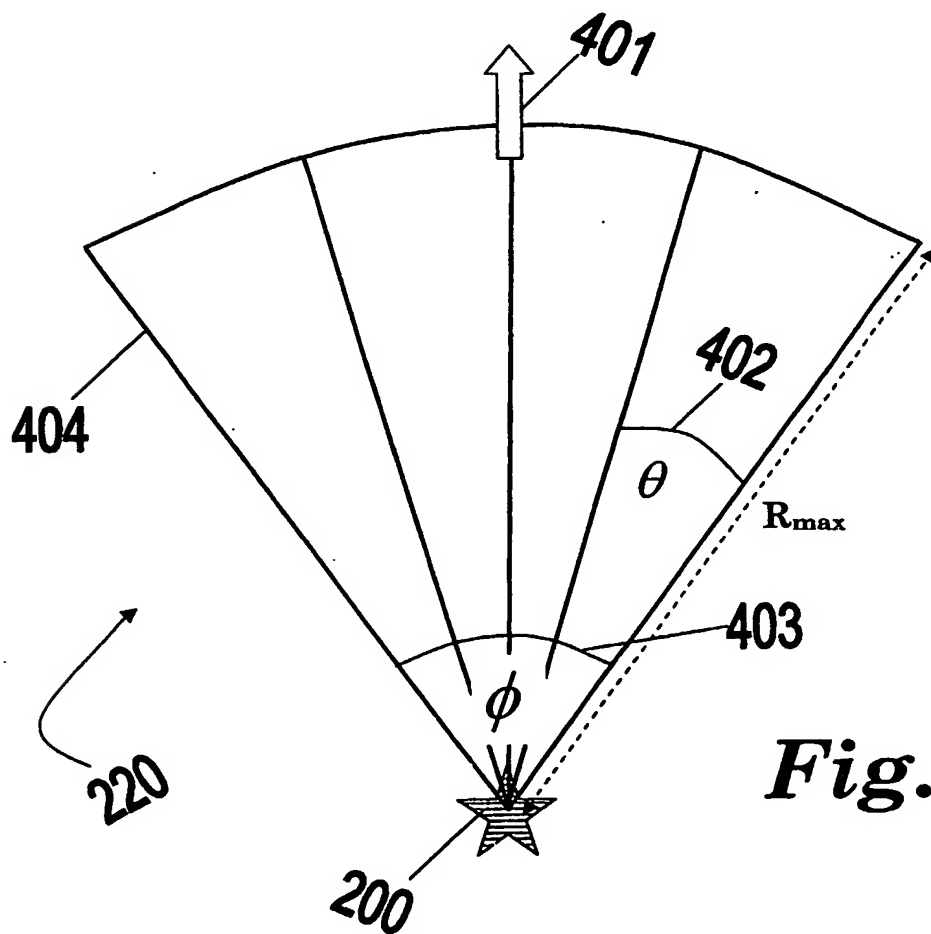
**Fig. 1A**

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*Fig. 2C**Fig. 2A*

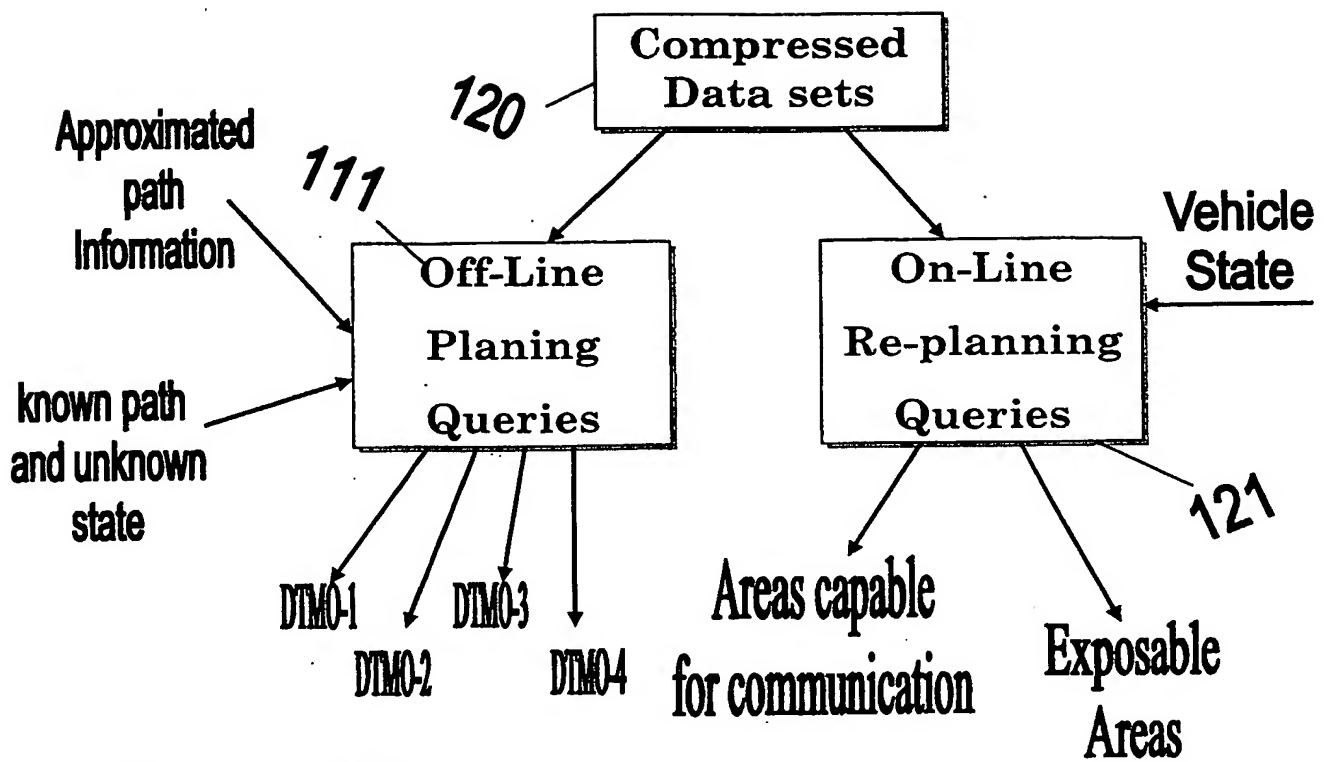
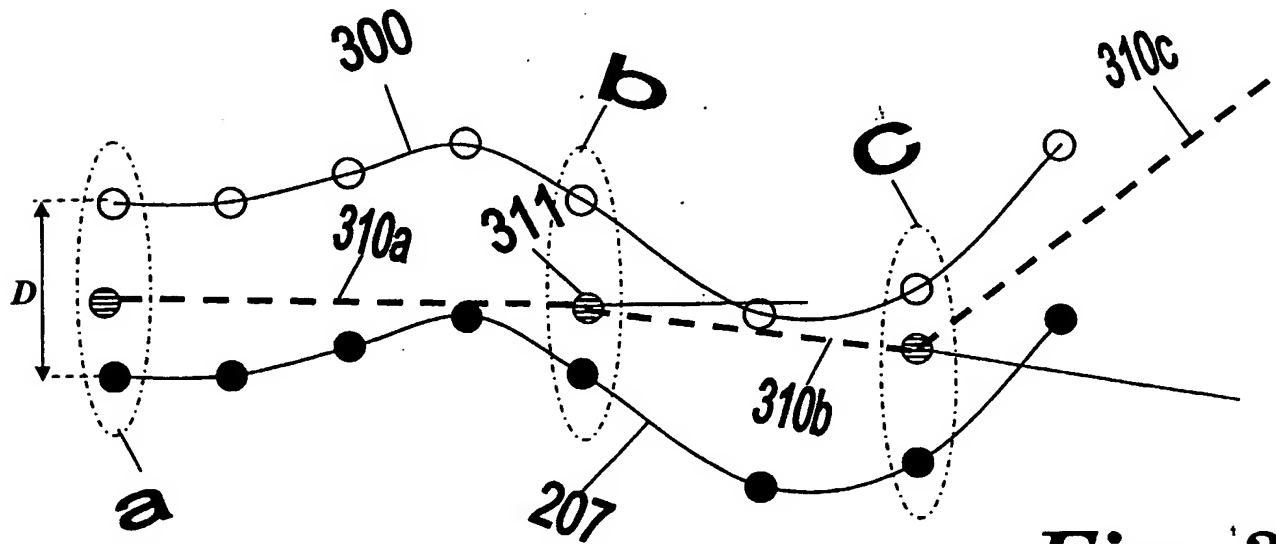


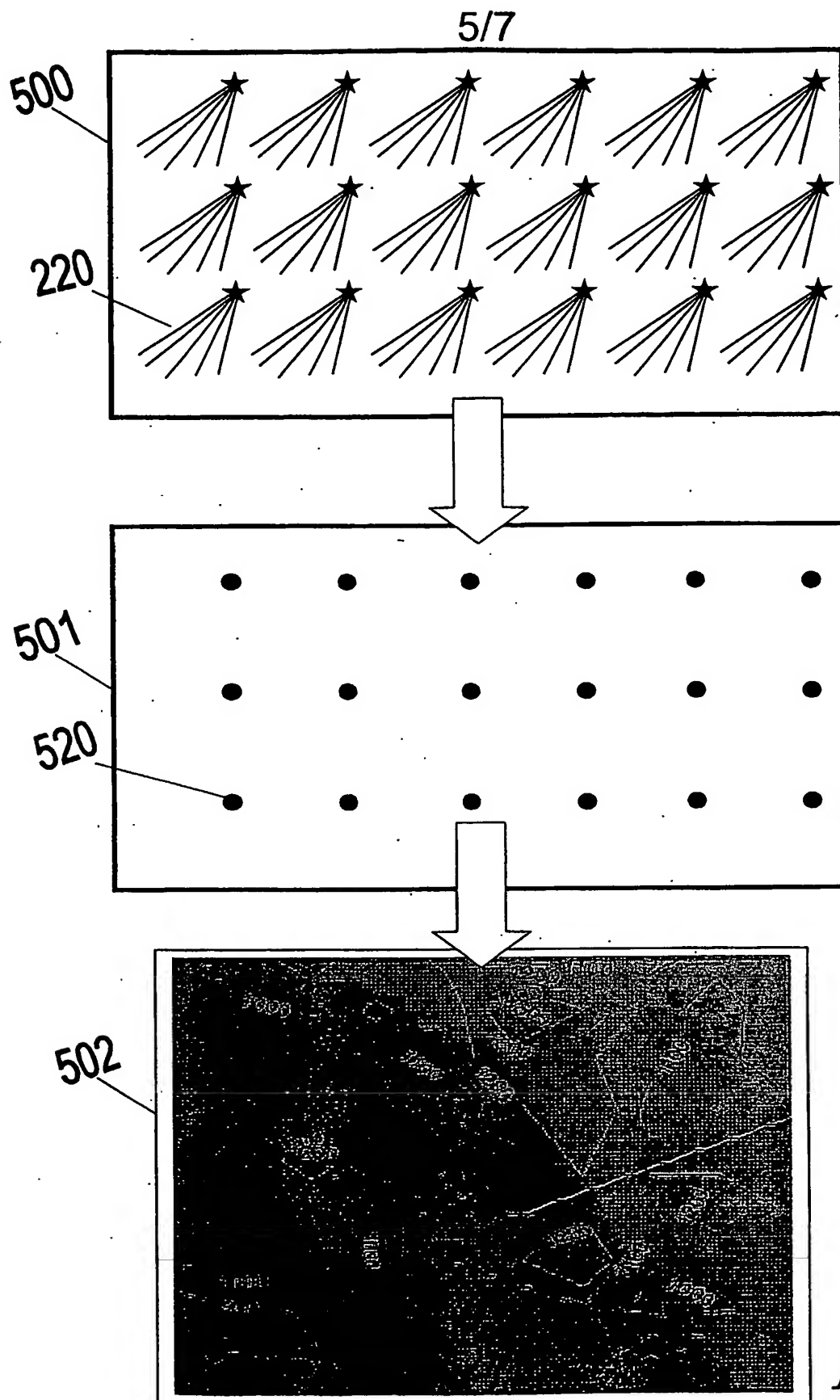
*Fig. 2B*



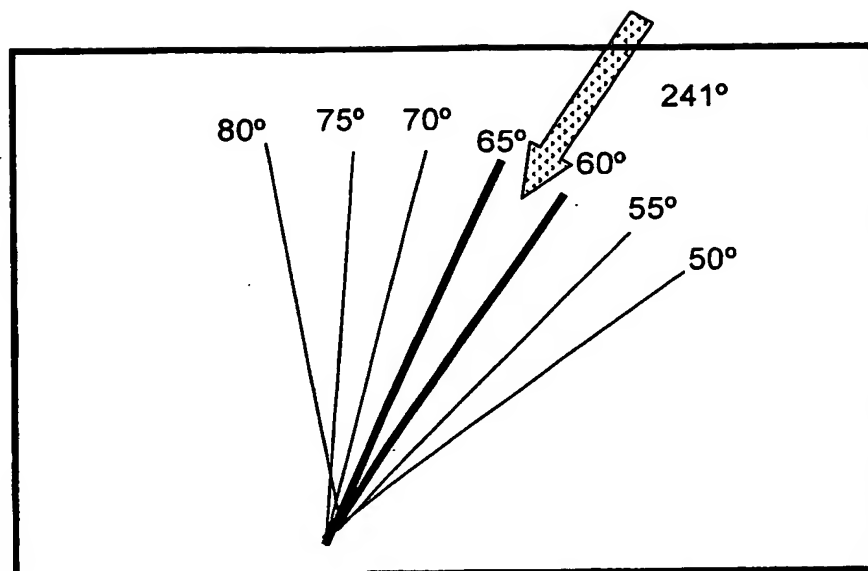
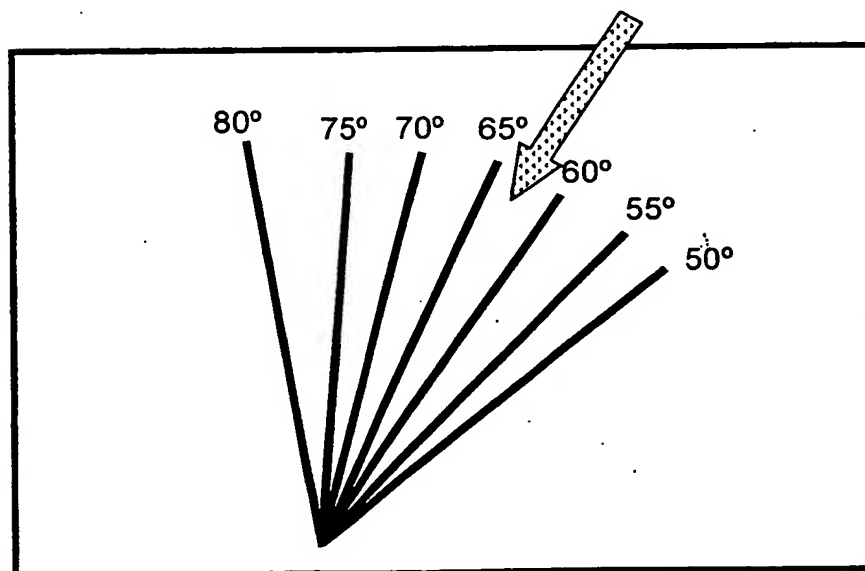
*Fig. 4*

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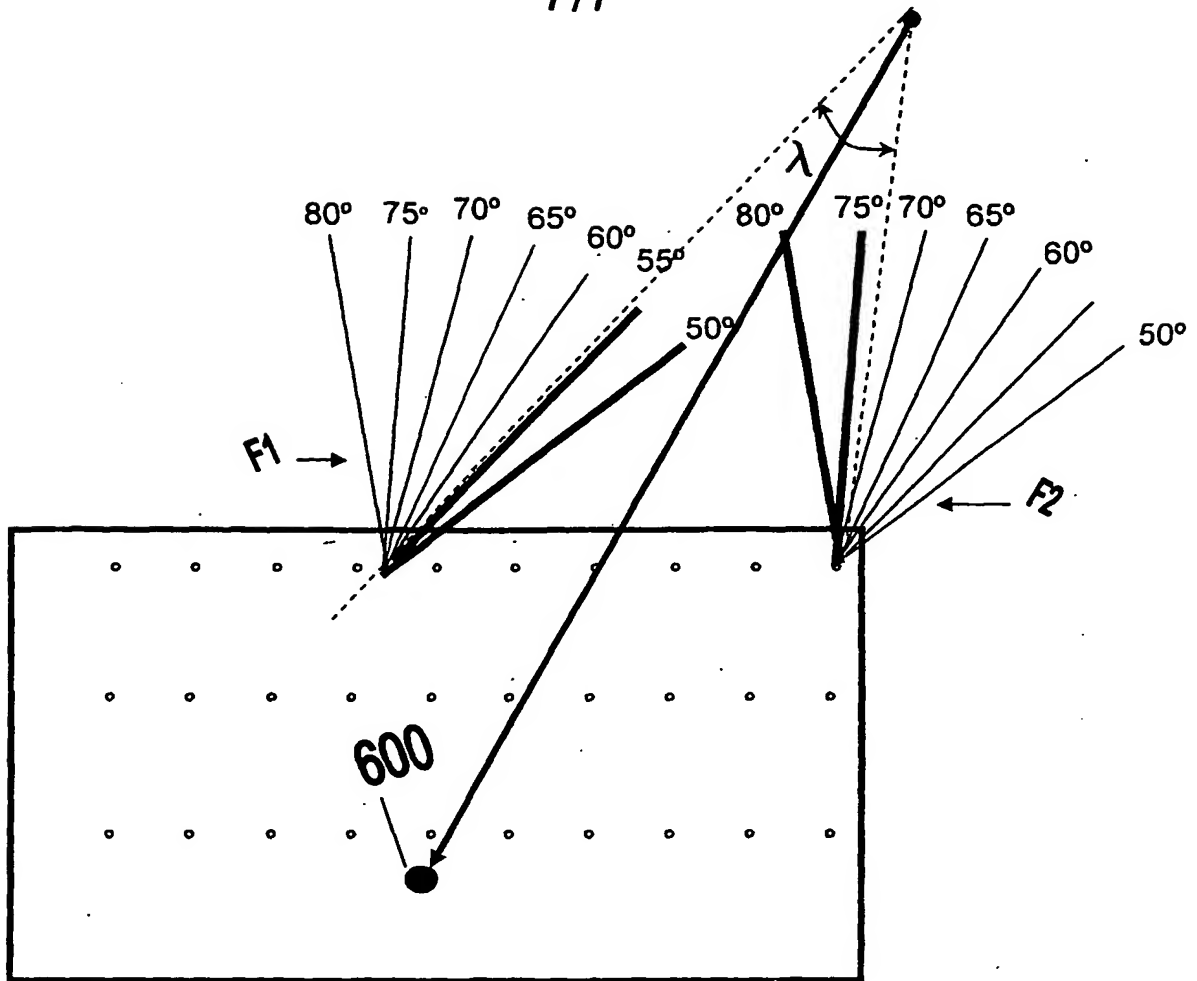
*Fig. 1B**Fig. 3*

**Fig. 5**

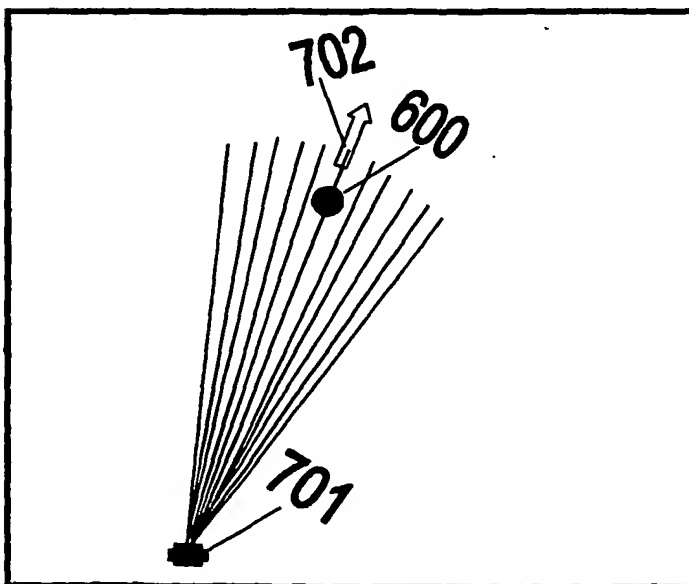
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*Fig. 6A**Fig. 6B*

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*Fig. 6C*



*Fig. 7*